AN INVESTIGATION INTO HUMAN HEART RATE RECOVERY AS A MEASURE OF WORK RATE

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ABSTRACT

Deney, Leonard Joseph, Jr. MS in Ind. Eng., Purdue University, June 1955. An Investigation into Human Heart Rate Recovery as a Measure of Work Rate. Major Professor: H. H. Young.

This investigation was designed to discover whether or not the human heart rate recovery could be used as a measure of work pace. As a person does work certain physiological changes take place within the body. One of these changes is that the heart rate increases above the normal rate as the work is being done. The heart rate recovery is the return of the heart rate or heart-beat back to the pre-exercise level. The average rate of recovery should follow the equation: $y = ae^{-kt} + b$, where y is the heart rate and t is the time after completion of the task[4]. The constants a, k, and b are characteristics of the individual and of the task completed.

The first step undertaken was the development of a standard task in which the operator's pace could be predetermined. This task consisted of operating a small hand pump located in a closed system filled with hydraulic fluid. The operator's pace could be arbitrarily fixed by requiring the operator to operate the hand pump at a given number of strokes per minute.

This was followed by the accumulation of experimental data obtained by having fourteen students serve as operators who completed the standard task in a series of prescribed work paces. These paces consisted of 80, 100, and 120 cycles or double pump strokes per minute and were particularly

chosen with the intent that the middle pace would be approximately a normal pace. These operators were chosen with no particular attributes or qualifications in mind. The group of operators chosen varied in age, height, weight, and physical condition.

An analysis of the results indicates a very high correlation between work pace and heart rate immediately following work. It is therefore concluded that a positive relationship exists between these two factors. The study indicates that heart rate may be used to predict operator pace under controlled conditions.

INTRODUCTION

During the past fifty years several physiological methods have been found to be indicators of the amount of energy expended in the accomplishment of physical work. Some of the physiological methods that might be used to measure human energy output and fatigue effects are discussed by Brouha and Ball[1].

> Physiological cost of muscular work can be accurately measured in laboratory experiments by combining various methods such as oxygen consumption, lactic acid concentration in the blood, increase in body temperature, amount of acceleration of the heart rate during work, and speed of deceleration of the heart rate after the work is over.
>
> The results presented in this paper show that simple measurements such as body temperature variations and heart rate recovery after work can be used to evaluate the physiological cost of muscular labor in industry.

To the best knowledge of the author, there has been only one attempt to date in which a comparison of the subjective method of rating has been made with a method based on physiological measurements of energy expenditure. This was conducted by C. J. Anson[2], who based his measurements on oxygen consumption. One of the conclusions reached in this investigation is that "--- because of the encumberance of the equipment necessary and of the length of time required to make a study, this technique is limited to laboratory investigations and is unsuitable for routine setting of standard times."

Since the heart rate or pulse immediately after work is considered to be one measure of physiological work, and because this measure is a relatively easy one to obtain, it

was decided to study this heart rate recovery after work to see if it might be used as an accurate measure of rate of work or pace in a controlled experiment.

Morehouse and Miller[3] indicate that the heart rate begins to accelerate immediately after the commencement of exercise. This acceleration then begins to level off after a few seconds and is then followed by a more gradual rise to a final maximal level. After the exercise is completed the heart rate then begins a recovery back to its normal level. This period of return back towards normal is defined as heart rate recovery. Johnson, Brouha, and Darling[4] have determined that for the first ten minutes of recovery the values of heart rate may be fitted with the exponential equation: $y = ae^{-kt} + b$, where a and b are constants, t is the time after stopping work, and k has dimensions of a velocity constant.

A summary of the physiological changes which take place in the body as work is done has been stated by Williams[5]:

> Body muscle exerts a force following the reception of electro-chemical impulses from the nervous system by the many muscle fibrils (of which the normally understood muscle is composed) which causes them to contract. The contractions are accompanied by a complicated chemical action in which glycogen (representing potential energy) stored in the fibril breaks down with the formation of lactic acid and heat.
>
> The fibril, in order to do further work, must recover from this exhaustion of potential energy (which we know in its gross manifestation as fatigue) by converting lactic acid back to glycogen. This recovery is accomplished using a supply of oxygen obtained from the blood stream; in the conversion carbon dioxide is formed and carried away by the blood. The lactic acid conversion to glycogen is accompanied by a further formation of heat which is in excess of that formed in the initial breakdown.

The blood, besides acting as a vehicle for oxygen and carbon dioxide between muscle and lungs, helps to regulate the muscle temperature by convection. The carbon dioxide is carried in solution by the blood to the lungs, where it is expired by the breath: the blood is then oxygenated by the blood haemoglobin becoming oxyhaemoglobin, and in this for oxygen is carried back to the muscle. The oxyhaemoglobin, after giving up oxygen to the muscle becomes haemoglobin and returns to the lungs for a repetition of the cycle.

The greater the force exerted by the muscle the greater is the breakdown of glycogen, the formation of carbon dioxide and the need for oxygen so that the lung ventilation rate must increase which results in quicker and deeper breathing. The limiting factor in the force that can be exerted by the muscle is its size and the blood supply to it. The blood supply is regulated primarily by the heart beat -------.

Aside from work load there are many factors that are known to increase fatigue and in effect vary heart rate recovery. Brouha[6] mentions such factors as; temperature, humidity, impervious clothing, sex, age, state of nutrition, and exposure to certain chemicals. Other factors that may cause the heart rate recovery to vary are; physical condition, time of day, self-consciousness, emotion, accumulated fatigue, and training. Most of these variables are thought to be of primary interest when trying to consider people as a group or when trying to compare two different persons. When considering one person alone at one particular time it was felt that randomization of the variable (pace) would tend to minimize these outside effects or factors. Factors like self-consciousness, state of nutrition, emotion, and physical condition which cannot easily be measured were left to be accounted for as part of the experimental error.

Any other factors such as dust, noise, vibration, smoke, and fumes which were not present and whose effect is generally not known were not considered.

PURPOSE

The purpose of this investigation was to investigate the assumption that heart rate recovery could be used as a measure of work pace. If this assumption could be substantiated, two practical uses of the relationship between heart rate recovery and work pace become possible. The first of these is in Time Study systems that have a provision for fatigue allowance. Such fatigue allowance might quite properly be based on the amount of physiological effort expended by the worker as indicated by the heart rate recovery for a given pace.

The second possible use would be in the construction of a rating system based on the physiological effort or stress imposed on the worker in accomplishing his particular task.

Both of these uses would require management, with the cooperation of the union, to establish some standard task that would fulfill the following requirements: The operator's pace should be capable of being measured and varied and the method used by the operator should be such that changes in pace do not require changes in method. With this task a certain work rate could be established as normal and a scale of values or increments above and below this could be established. In use, the worker's heart rate recovery could be determined after he had operated his particular piece of equipment for a prescribed amount of time. After an adequate rest period the worker would then be requested to operate the standard task under identical working conditions at various known fixed rates that would most likely bracket his particular

pace. These resulting heart rate recovery values when plotted over the recovery curve resulting from the actual job should then give a physiological indication of the actual pace of the worker compared with the known and accepted standard pace on the standard task since both the tasks were performed at nearly the same time and under similar conditions.

When used for fatigue allowance a normal level of fatigue could be decided upon. Whenever heart rate recovery curves were significantly higher than this level, fatigue allowances could be applied.

A third use of heart rate recovery has been recommended and used by Brouha[1]. He found that heart rate recovery measurements and body temperature changes can be used to measure the effectiveness of rest periods. Such measurements are also useful in determining the effectiveness of improved work methods or improved tools and machinery as far as reducing the physiological costs of the various jobs. In using this technique the heart rate recovery curve could be determined for the old method at a particular pace. Using this same pace the heart rate recovery curve could be determined for the new method. If under the new method the resulting recovery curve were equal to or lower than the one for the old method the new method would require less physiological effort. A further lowering of the curve or the amount of physiological effort required should occur as the worker learns the new method.

DESCRIPTION OF APPARATUS

The apparatus used in this investigation was purposely kept as simple as possible. To provide a task which would require a uniform amount of physical effort, a double-acting hand hydraulic pump was used. The type of pump used was one readily available as surplus material, an aircraft emergency hand hydraulic pump. This pump could be operated at any pressure up to 2000 pounds per square inch and had a capacity of 1.5 cubic inches of fluid for each complete cycle. This pump was installed in a closed circuit. Both the inlet and outlet sides of the pump were connected to a one gallon container by 3/8 inch copper tubing. A brass plug was placed in the end of the output line. A small orfice was then drilled in this plug so as to allow fluid flow but still restrict the flow enough to require a certain amount of effort to circulate the fluid. This hole was approximately .028 inches in diameter. The container was filled with standard aircraft hydraulic fluid and then sealed.

The pump, container, and lines were than mounted on a plywood sheet supported on a pipe frame. This table should have preferably been one that was adjustable in height. As this was not available a base plate was made on which the operator stood. The construction of this was such that it could be varied in height as required.

The remainder of the equipment consisted of a metronome, a decimal-minute stop watch, and an electric clock calibrated in hundredths of a second with a solenoid start-stop circuit.

Figures 1 and 2 illustrate the equipment photographed from two positions. Figure 3 shows an operator in proper position for making a test run.

Figure 1. Equipment Layout

Figure 2. Equipment Layout

Figure 3. Operator Position

PROCEDURE

As each operator entered the room in which the apparatus was located he was asked to step over to the equipment and was given the following instructions:

If you will please step over here I will give you a brief description of the test apparatus that you will operate. Here is a double action hydraulic hand pump whose inlet side is connected to the bottom of this container. The outlet side of the pump leads to the top of the container. At the end of this line there has been placed a plug with an orfice drilled in it. This orfice is approximately .028 inches in diameter and is that small so that a reasonable amount of force will be required to operate the pump.

Now to describe what you are to do. With the aid of the metronome three different paces will be established. At each different pace you are to operate the pump in synchronization with the metronome. You will be given a ten minute rest period between each different pace. A fourth operation will consist of you setting your own pace. Each of these operations will be performed for a period of two minutes at the end of which time you will be told to stop and your heart beat will be timed for a period of approximately four minutes. During your first rest period I will briefly explain the purpose of this experiment.

Now, for a brief practice session. Place your feet within the black footprints and place your left hand on the handprint there on the table. With your right hand grasp the handle of the pump. Later while you are resting the platform height will be adjusted so that your right forearm will be parallel with the table top. Now operate the pump handle back and forth. Be sure in all the following runs to push the handle all the way forward and pull it all the way back. Now try to keep pace with the metronome. Use your whole body, push with your arm, shoulder, and back, twist at the waist. Ten minute rest period.

Additional instruction for optional pace: During this run you are to operate the pump at a speed of your own choosing. Set the pace that you are most comfortable at. This should be a pace that you would use if you had to operate this pump all morning (afternoon). Don't loaf on the job or try to set a speed record. Just operate the pump at the pace that is most comfortable to you.

Additional instruction for fast pace: This pace will be the fastest that you will be requested to maintain. It can

be done for three minutes so don't give up if you miss your timing occasionally. Do your best and try to keep time with the metronome and be sure to use full strokes.

This short set of instructions also served as an instruction period for the operator. During this period the operator practiced at the last pace set on the metronome from the previous operator. After the two minute training period the operator was then requested to sit down in a comfortable chair provided for the ten minute rest periods. The only activity that he was permitted during this period was that of conducting a normal conversation.

Between each pace it was decided to use a ten-minute rest period. This time was chosen such that the four different paces at two minutes each, plus a training period and the rest periods, could be done in one hour. This one hour period was most practical as the operators were all students with short periods of free time. It was further felt that the ten minute rest period was of sufficient length to allow the heart rate to return to some point near the normal level and for any oxygen debt which may have been incurred to be sufficiently replenished. Hill[7] indicates that, following the cessation of exhausting exercise, the recovery of oxygen is 46 per cent complete in 5 minutes, 64 per cent complete in 10 minutes, and 80 per cent complete in 20 minutes. This task was not considered exhausting and was performed at paces that are close to the optimal speed at which the oxygen requirement is minimal. Morehouse and Miller[3] point out that the worker usually automatically adopts the optimal pace of working and

that as the pace increases or decreases the mechanical efficiency is diminished and the oxygen requirement increased. One of the purposes of the optional pace was an attempt to establish the operator's optimum pace. Johnson, Brouha, and Darling[4] present data for heart rate recovery after exhausting exercise and indicate that after exhausting exercise the heart rate recovery curve begins to become asymptotic between 5 and 10 minutes after stopping work.

The platform upon which the operator stood was adjusted in height so that his forearm would be approximately horizontal when the pump handle was in the vertical position. Figure 3 indicates the proper body and forearm position.

By requiring the operator to complete a certain number of strokes in a fixed interval of time the operator's pace could be prescribed and varied as needed. This was done by having the operator keep time with a metronome. It was decided, because of time limitations, to use three different paces at twenty per cent increments. These three paces, besides being at twenty per cent increments of pace, should also theoretically be in twenty per cent increments of useful work output. The useful work would be in the amount of fluid transferred if the system were not a closed loop. It was also hoped that the difference in the amount of energy expended between paces involved would be in twenty per cent increments. This was not measured but is assumed to be as close as can be attained with most types of devices where an increase in pace involves an increase in the accelerations and velocities of the moving

parts.

The different paces that the operator had to maintain were numbered as follows: (1) 120 cycles per minute, (2) 100 cycles per minute, (3) 80 cycles per minute, and (4) an optional pace. The order in which these different paces were performed was selected at random through the use of a table of random numbers[8]. This was done in an attempt to minimize the effects of cumulative fatigue and training experience in the data.

The method of timing employed was to start the stop watch when the operator started operating the pump; at the end of two minutes the operator was told to stop and face the observer. At exactly ten one-hundredths of a minute after cessation of work, the electric clock was started and the time for the operator's heart to beat 30 times was recorded in hundredths of seconds using a stethoscope to pick up the heart beat.

It was found that slightly less than ten one-hundredths of a minute was necessary to locate the stethoscope on the chest for the best reception of the heart beat and to get the operator in proper position. The successive timings of 1, 2, and 3 minutes after cessation of work were measured from this ten one-hundredths of a minute point. It is to be noted that no appreciable error is introduced by not timing immediately upon completion of the work period. "---heart rate falls very little during the first ten seconds after work, and for the next ten seconds only about six per cent.[9]" During the rest period between the second and third paces,

the wet and dry bulb temperatures were recorded so as to have data available with which to determine the possible effect of humidity and temperature on the results.

The additional instructions given prior to the fast pace were thought necessary so that the operator would not become discouraged if he was not able to maintain exact synchronization with the metronome.

RESULTS AND CONCLUSIONS

Fourteen operators were requested to operate the standard task at three given paces and at one pace of their own choosing. Table I is a compilation of the personal data concerning these operators. Table II is a summary of the resultant heart rates for these operators at the four paces. The numbers 0 through 3 are the number of minutes after completion of the tasks at which the heart rate was measured. Pace 1 is at 120 cycles per minute, pace 2 is 100 cycles per minute, pace 3 is 80 cycles per minute, and pace 4 is the optional pace. The last column in this table is an approximation of the optional pace. The approximation was obtained by counting the number of pump strokes made by the operator for a period of one-half minute, from one to one and one-half minutes after the pace was started.

The means of each of the heart rates for each pace and time were calculated and are presented in Table III. A plot of this data is presented in Figure 4. There has been no attempt to determine the mean value of the heart rate for the optional pace, as each operator chose a different pace. It can be seen from this Figure that the data for the 80 cycles-per-minute pace does not follow a smooth curve. It is the belief of the writer that this pace may be close to the minimum pace for this particular job, at which heart rate and pace are related. At this minimum pace other factors such as emotion and self-consciousness may over-shadow the effect of pace on heart rate. This is especially true as

the time after the completion of the task increases and the heart rate is very near its normal level.

Brouha and Heath[10] state that, "The influence of common emotional factors on the heart rate is often underestimated--." Schneider and Karpovich[11] also state that, "If only the postexercise pulse rate is used, the exercise should be strenuous enough to obliterate the possible effects of emotional factors."

Figures 5 through 18 are the curves obtained for the heart rate recovery for each of the fourteen operators. The numbers on these curves indicate the pace at which each of the curves was obtained.

It is interesting to note in Figure 5, and in others, that the change in heart rate at zero time when the pace is increased from 80 to 100 cycles per minute is not equal to the change in heart rate for the change from 100 to 120 cycles per minute.

Figure 16 indicates an opposite type of inequality in that the increase from 100 to 120 cycles per minute results in a greater increase in physiological stress than results from the 20 per cent increase in pace from 80 to 100 cycles per minute.

It should be noted at this time that Anson[2] found by means of studies of oxygen consumption that when his values obtained for different work rates were compared with the average of a number of ratings assigned by time study men for these work rates that a linear relationship between the two did not exist.

TABLE I

Summary of Operator Data

Operator	Age	Height	Weight	Date Observed	Time Started	Temp. °F	Humidity
1	23	5'6½"	165	3/30	11:00a.m.	66	70
2	27	5'3½"	175	3/30	1:00p.m.	70½	58
3	26	6'0"	185	3/30	2:00p.m.	71½	57
4	34	5'7"	145	3/30	3:00p.m.	71½	57
5	22	5'10½"	165	3/31	10:00a.m.	68	69
6	24	5'10"	185	3/31	11:00a.m.	74	59
7	22	5'11"	165	3/31	1:00p.m.	72	62
8	31	6'1"	172	4/1	11:00a.m.	72½	39
9	21	5'8"	155	4/4	1:00p.m.	69½	49
10	21	6'0"	180	4/4	3:00p.m.	69½	42
11	27	5'8"	174	4/5	10:00a.m.	70½	60
12	23	6'3"	215	4/5	1:00p.m.	74	37
13	23	6'0"	205	4/5	2:00p.m.	75½	39
14	31	6'5"	230	4/8	1:00p.m.	75	70

TABLE II

Heart Rate, Time, and Pace

Operator	Pace	Time 0	Time 1	Time 2	Time 3	Pace
1	3	21.70	25.12	- -	25.05	
	2	15.77	18.31	22.86	22.23	
	1	12.10	15.90	18.51	18.36	
	4	17.29	20.99	21.13	21.33	92
2	3	18.94	19.62	19.34	19.64	
	4	16.62	17.50	20.70	20.93	104
	1	16.21	16.73	18.34	18.83	
	2	16.63	18.00	19.17	19.36	
3	3	15.90	19.36	19.40	20.03	
	2	14.30	17.87	20.26	19.27	
	1	12.96	15.54	16.90	17.22	
	4	16.00	20.80	19.05	19.74	76
4	1	13.00	15.65	16.98	19.42	
	2	17.64	19.60	20.53	20.00	
	4	16.57	20.74	20.68	20.60	100
	3	20.44	21.50	21.24	21.67	
5	2	17.74	22.12	24.31	24.08	
	1	14.52	17.47	18.25	24.08	
	4	15.56	19.40	20.94	21.47	108
	3	19.36	21.58	21.95	22.53	
6	3	20.69	24.14	24.77	23.48	
	4	18.46	20.96	21.43	20.83	94
	2	15.79	19.02	20.00	20.60	
	1	13.15	15.73	17.06	18.04	
7	4	15.74	17.37	18.61	19.15	96
	1	10.66	13.62	14.14	15.06	
	2	12.58	15.30	16.55	17.06	
	3	14.75	16.56	16.54	- -	
8	2	22.83	25.36	30.33	30.29	
	4	24.10	28.44	29.44	27.04	78
	3	23.95	26.57	27.66	27.20	
	1	20.92	26.31	25.53	25.62	
9	2	16.40	20.59	22.10	23.93	
	1	13.82	19.62	24.56	24.06	
	4	20.13	22.38	22.48	22.43	100
	3	20.20	22.03	22.94	23.57	

TABLE II (continued)

Heart Rate, Time, and Pace

Operator	Pace	Time				Pace
		0	1	2	3	
10	4	18.21	22.34	22.73	22.79	84
	1	14.20	15.68	18.16	17.34	
	2	14.40	16.75	18.37	18.67	
	3	17.92	17.78	18.72	19.39	
11	3	22.76	26.12	26.30	26.60	
	2	18.50	22.55	23.28	23.78	
	1	14.96	19.96	22.16	22.92	
	4	16.92	22.54	21.64	23.61	94
12	3	18.21	19.46	20.70	20.18	
	2	16.61	18.44	18.76	19.36	
	1	13.28	14.97	17.59	18.64	
	4	14.79	16.78	17.75	19.05	102
13	4	18.44	21.76	21.85	21.40	80
	3	18.27	21.90	21.60	21.46	
	2	16.34	21.00	22.11	21.66	
	1	14.61	22.68	21.28	21.85	
14	1	11.53	15.80	18.21	18.10	
	3	16.73	19.83	20.57	20.91	
	4	14.11	17.98	18.61	20.07	98
	2	14.48	19.30	20.45	19.83	

TABLE III

Mean Heart Rate

Pace	Time (sec.)			
	0	1	2	3
1	13.99	17.55	19.12	20.02
2	16.55	19.62	21.40	21.47
3	19.27	21.54	21.72	22.44

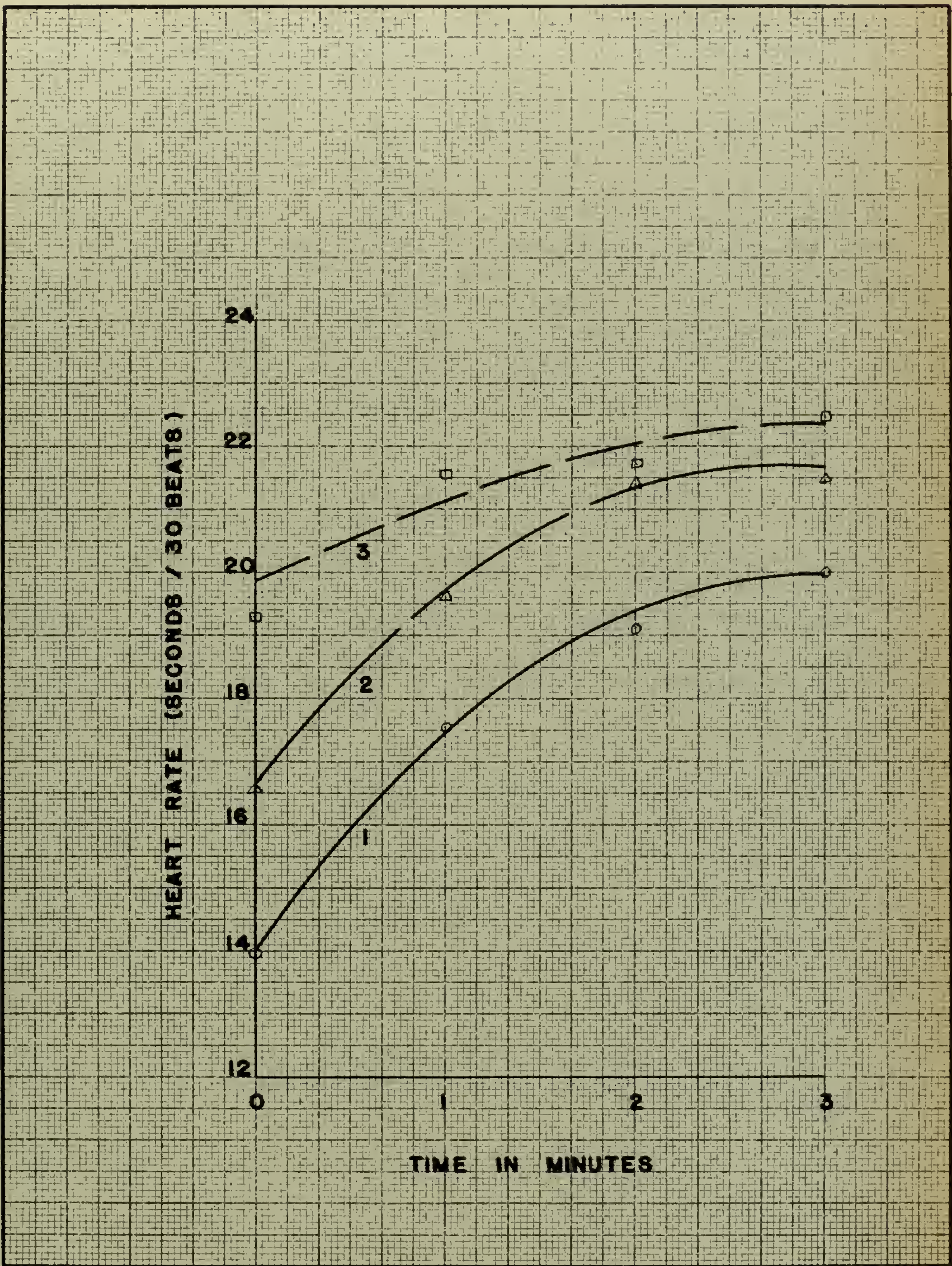

Figure 4. Mean Heart Rate vs. Time

To determine if the difference between the means of the values of heart rate for the change from 80 to 100 cycles per minute were significantly different from the difference in means of the heart rates for the change from 100 to 120 cycles per minute at zero time a test to determine the significance of the difference between the means of small samples was made. This test indicated that there was no significant difference.

An analysis of variance for a one-way classification of data was run to test the hypothesis that the means of the heart rates taken at zero time are not significantly different for each of the three given paces. The criterion "F" value at a 5% level of significance was 3.24. The test ratio was found to have a value of 15.8, indicating a highly significant effect of pace upon heart rate. Appendix A contains the calculations used in this analysis and the analysis of variance table.

Table IV contains the correlations found between pace and heart rate at the cessation of work (zero time) and at one minute after completion of the task. The computation of the correlation factors was done using the method of "Computation of r directly from raw data" described by Tiffin[12]. Appendix B contains the calculations for these correlations, which varied from .999 to .839 for the fourteen operators immediately after work. One minute after the task was completed these correlations varied from .999 to .363. As the time increased after work completion the correlations became of less value in some cases. These have not been computed but indications are clearly present in Figures 5

TABLE IV

Correlations between Rate and Pace at 0 and 1 Minute after Cessation of Work

Operator	Correlations	
	r_0	r_1
1	.9910	.9641
2	.9291	.9972
3	.9873	.9918
4	.9900	.9802
5	.9950	.8081
6	.9903	.9922
7	.9992	.9964
8	.9886	.3629
9	.9941	.9944
10	.8887	.9999
11	.9886	.9958
12	.9803	.9537
13	.9922	.4645
14	.9972	.9200

through 18 where the heart rate recovery curves in some cases cross. These figures are the recovery curves for each operator. It is believed that had the work paces been higher, such as 120, 140, and 160 cycles per minute there would have been higher correlations for longer intervals of time after completion of the task. At these higher paces the physiological stress of the task would dominate other factors that affect heart rate recovery.

It is felt that Figure 10 illustrates the assumption that heart rate recovery is related to pace to a better extent than Figure 13 which has recovery curves that intersect themselves.

It might be inferred that a twenty per cent increment in pace is quite large and that pace might not have had such a high correlation with heart rate had the increments been smaller. With the exception of operators number 7 and 10, the heart rates at zero time were found to be in proper relationship with the approximate pace determined for the optional pace. In some cases this optional pace only differed by two per cent from one of the prescribed paces and discrimination still existed. Examples of this two per cent increment where work pace and heart rate are in proper relationship may be observed in the data for operators 1, 8, 12, and 14.

The data for the optional pace for operators 7 and 10 was found not to be in agreement with the data obtained for the other operators. One factor that might explain this discrepancy is that the optional pace for these two operators was the first operation attempted by them. There exists the

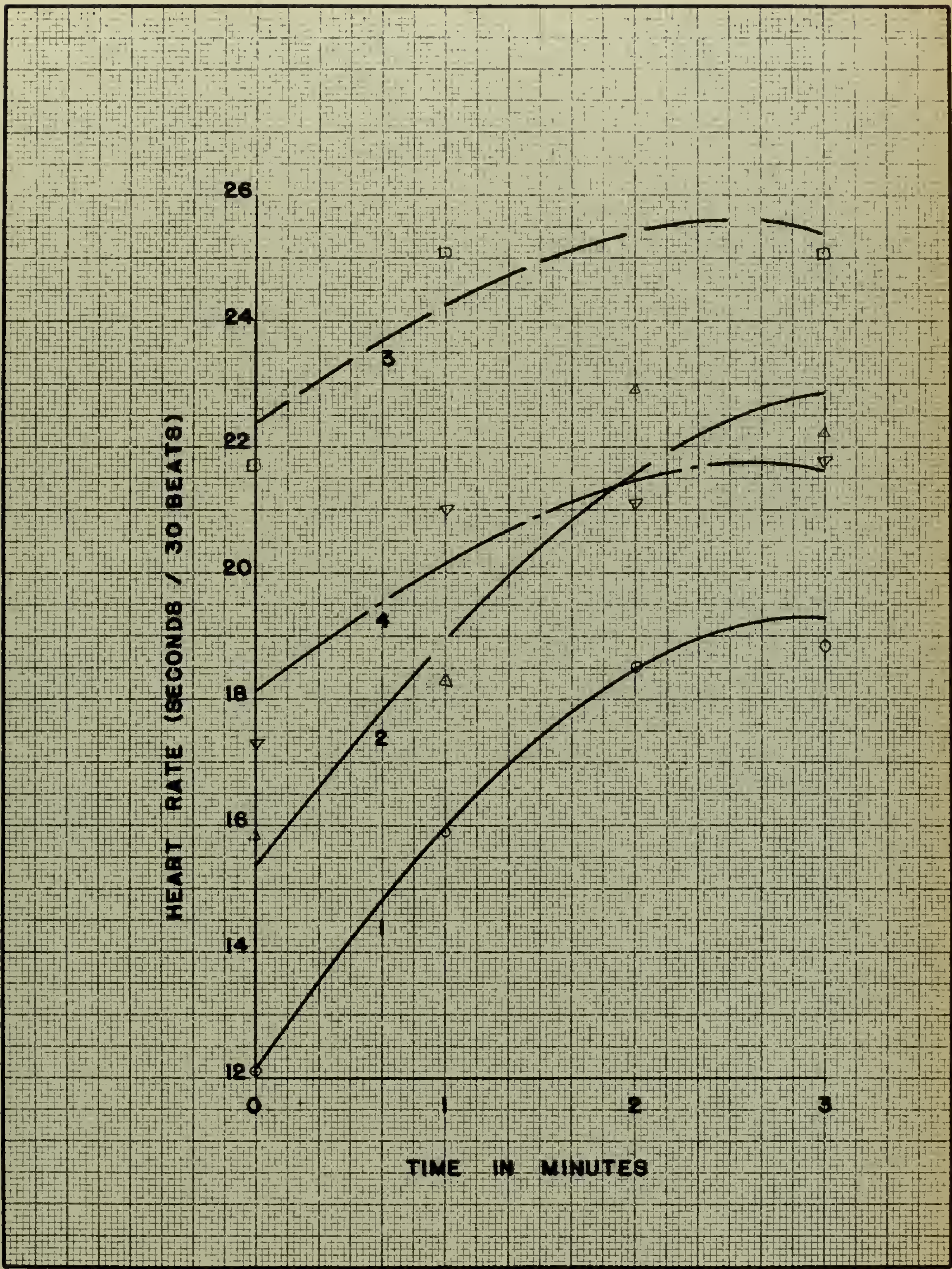

Figure 5. Heart Rate vs. Time: Operator No. 1

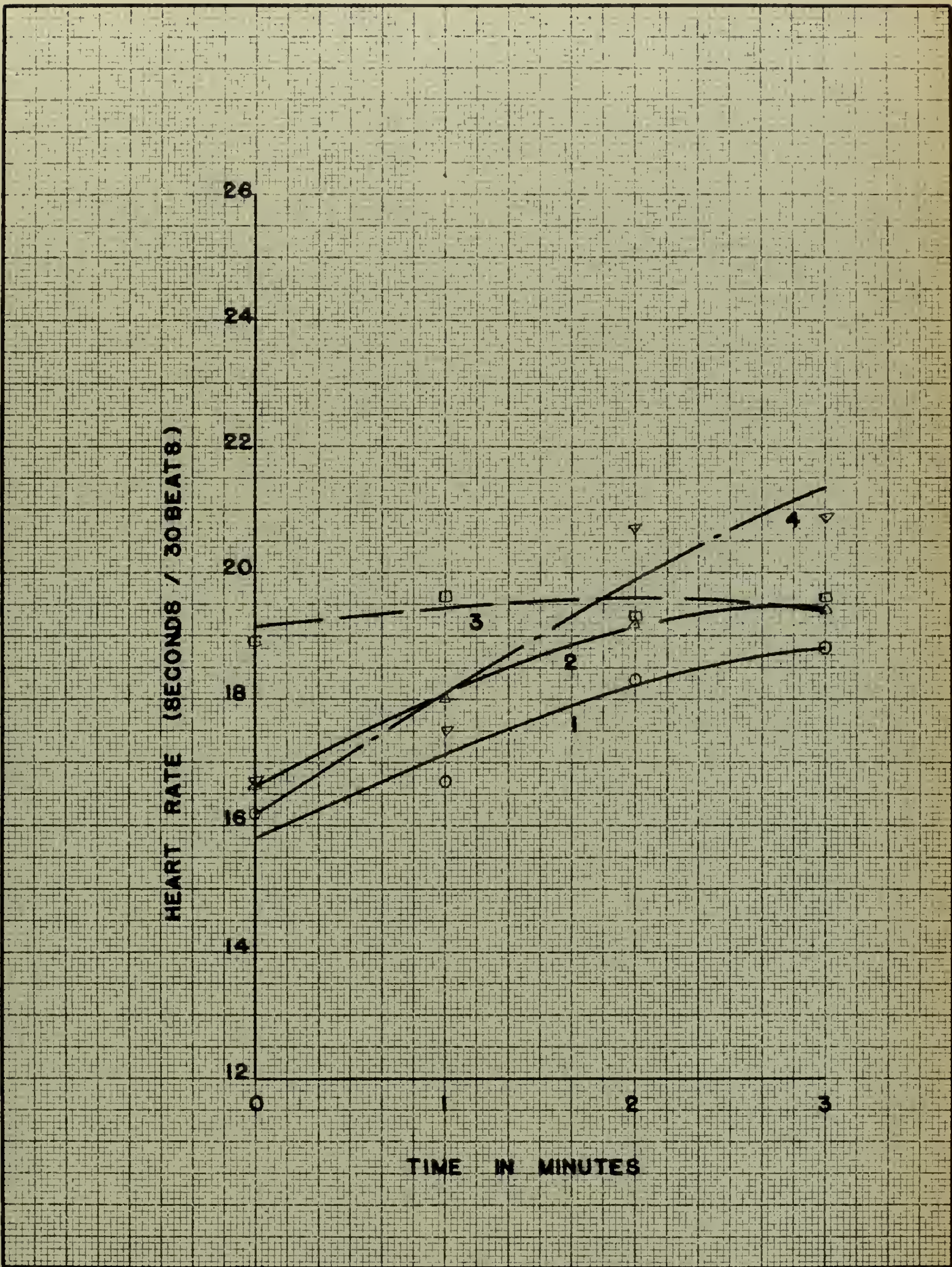

Figure 6. Heart Rate vs. Time: Operator No. 2

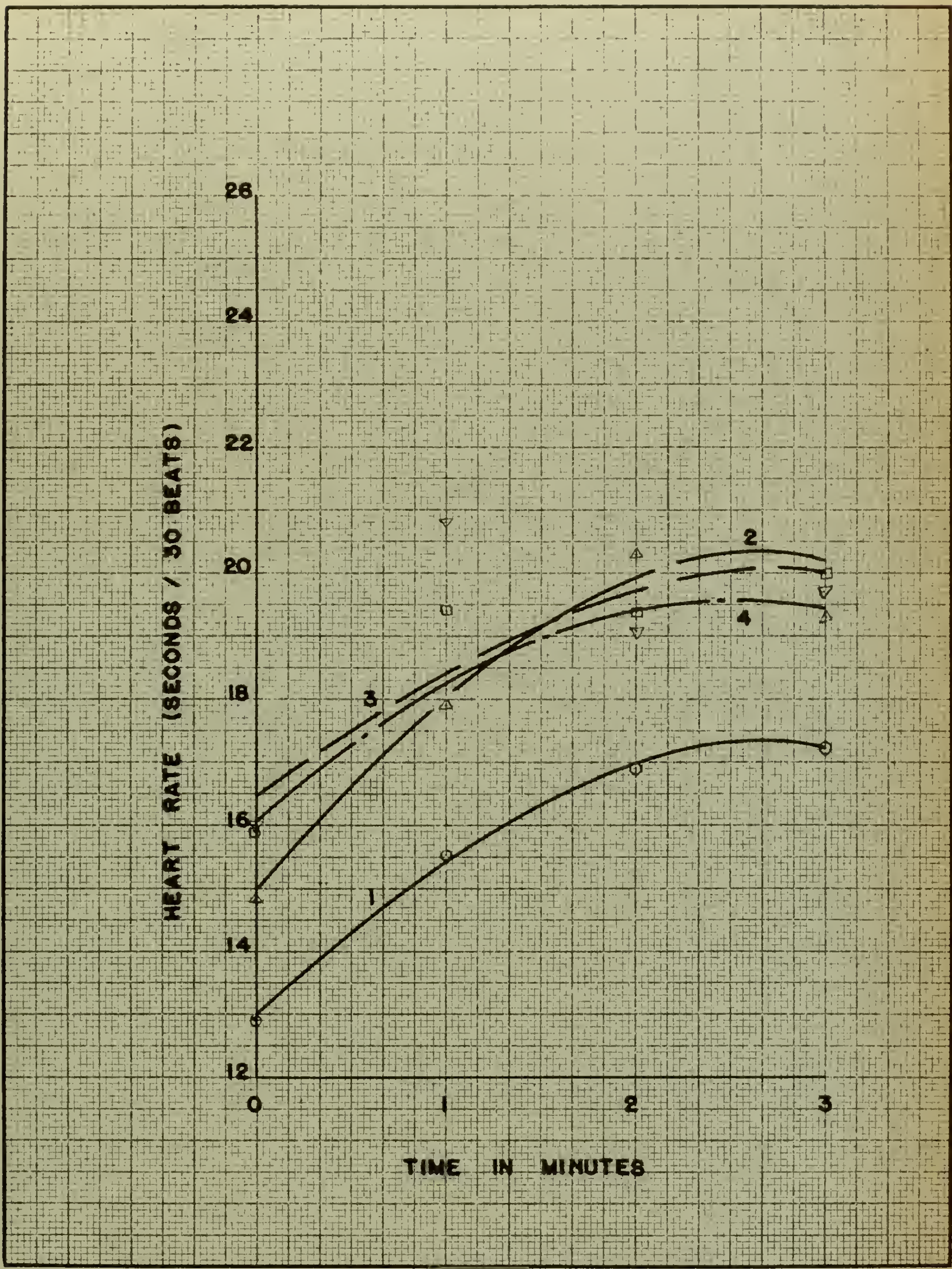

Figure 7. Heart Rate vs. Time: Operator No. 3

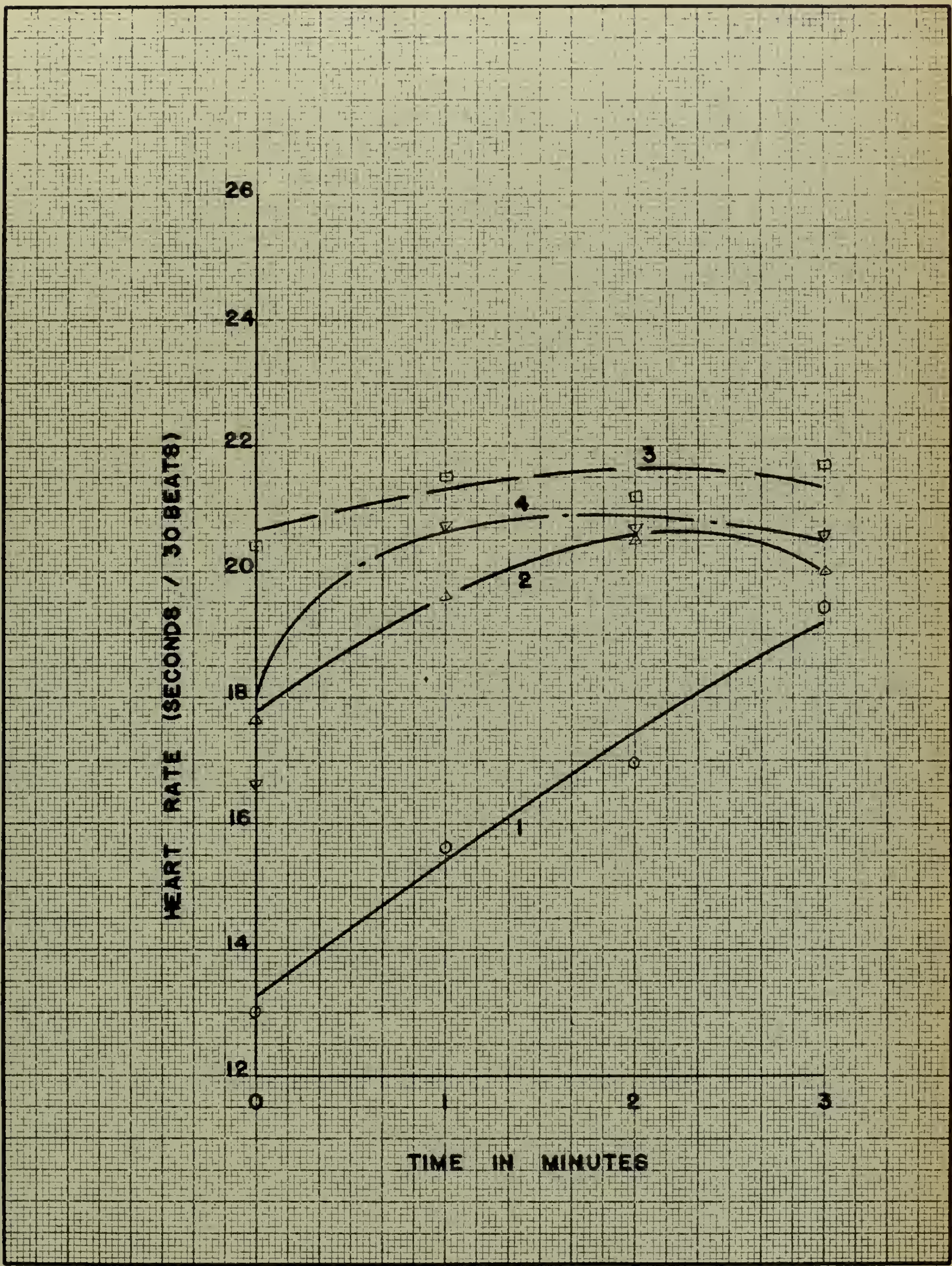

Figure 8. Heart Rate vs. Time: Operator No. 4

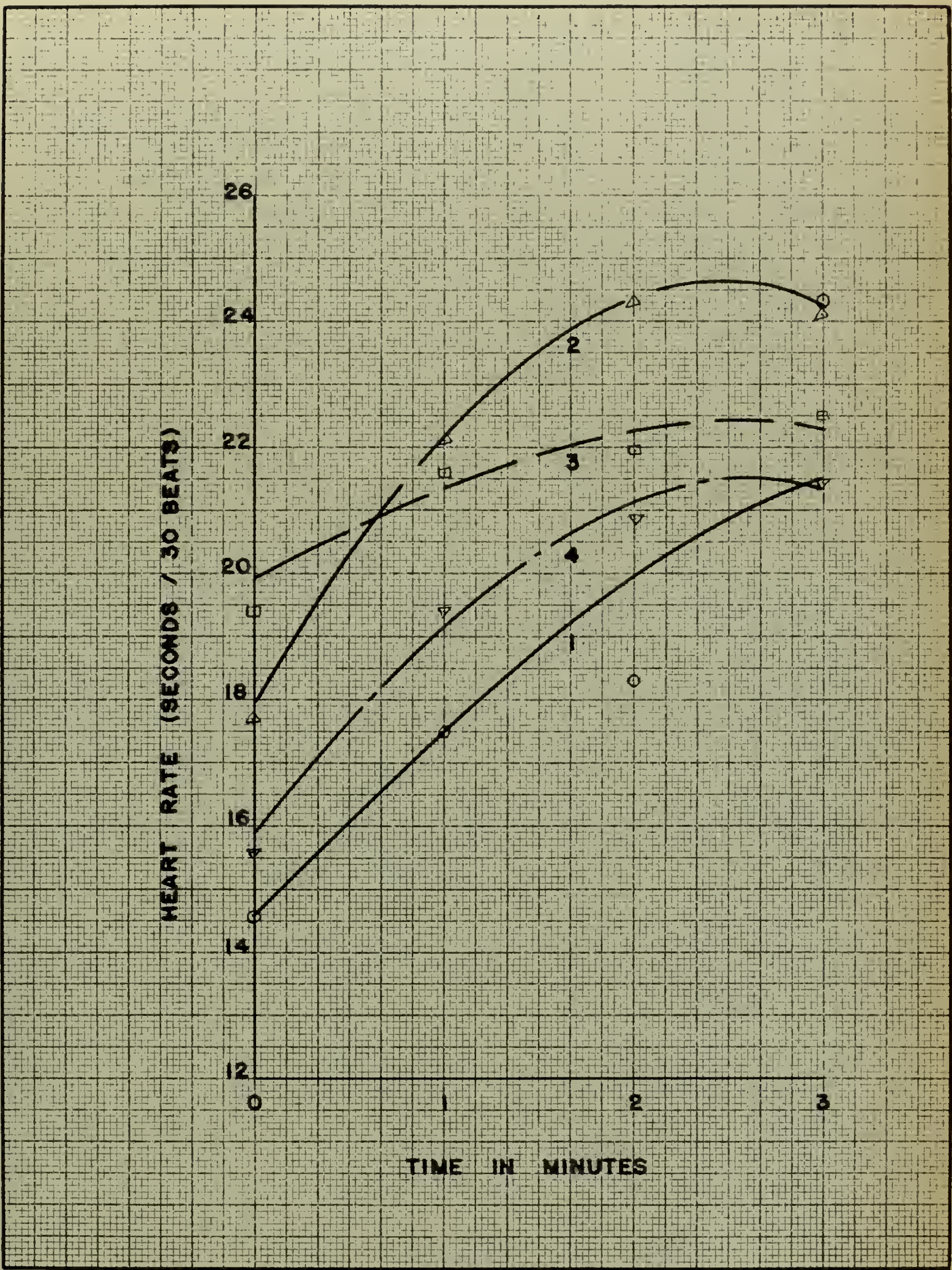

Figure 9. Heart Rate vs. Time: Operator No. 5

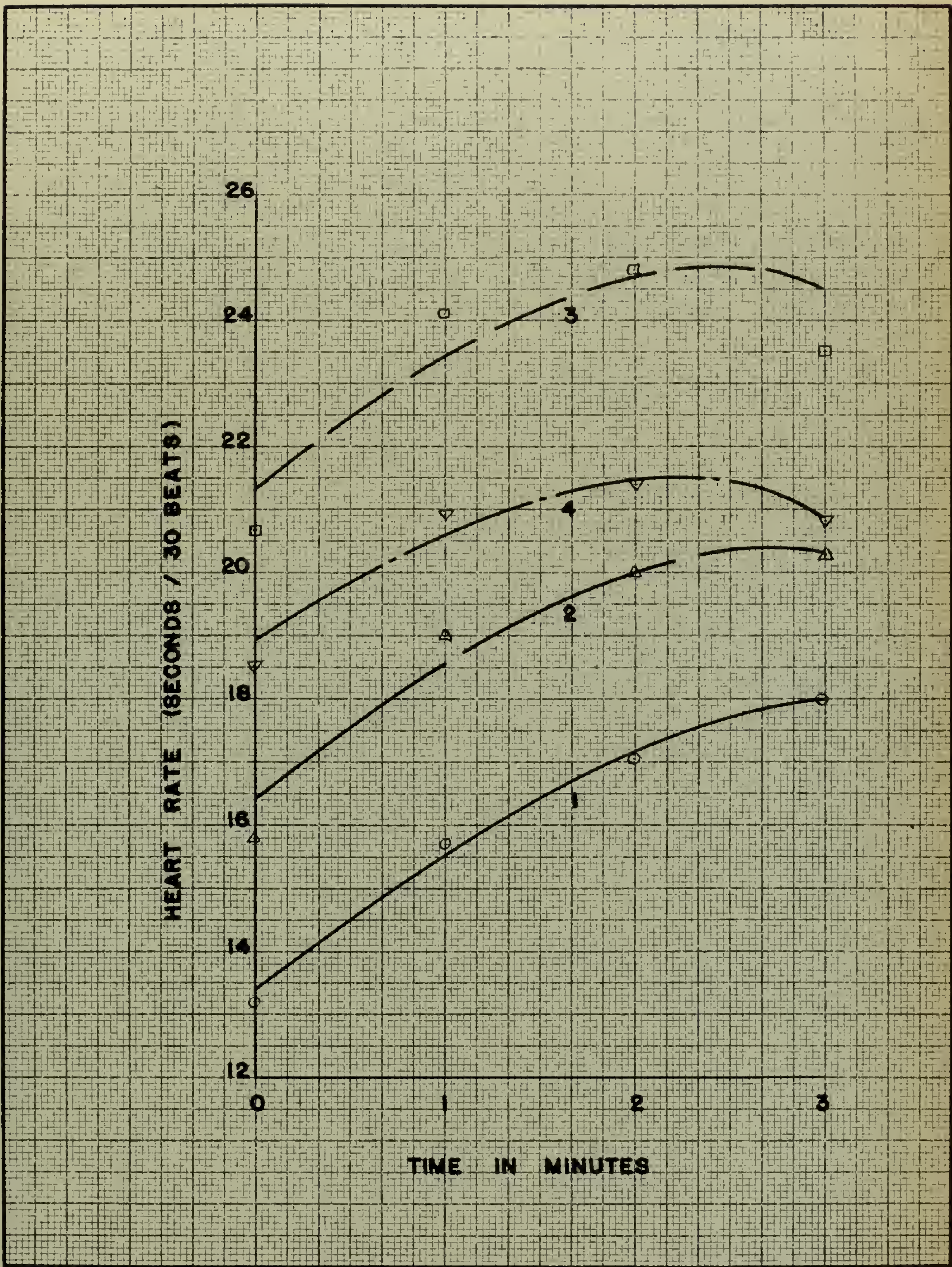

Figure 10. Heart Rate vs. Time: Operator No. 6

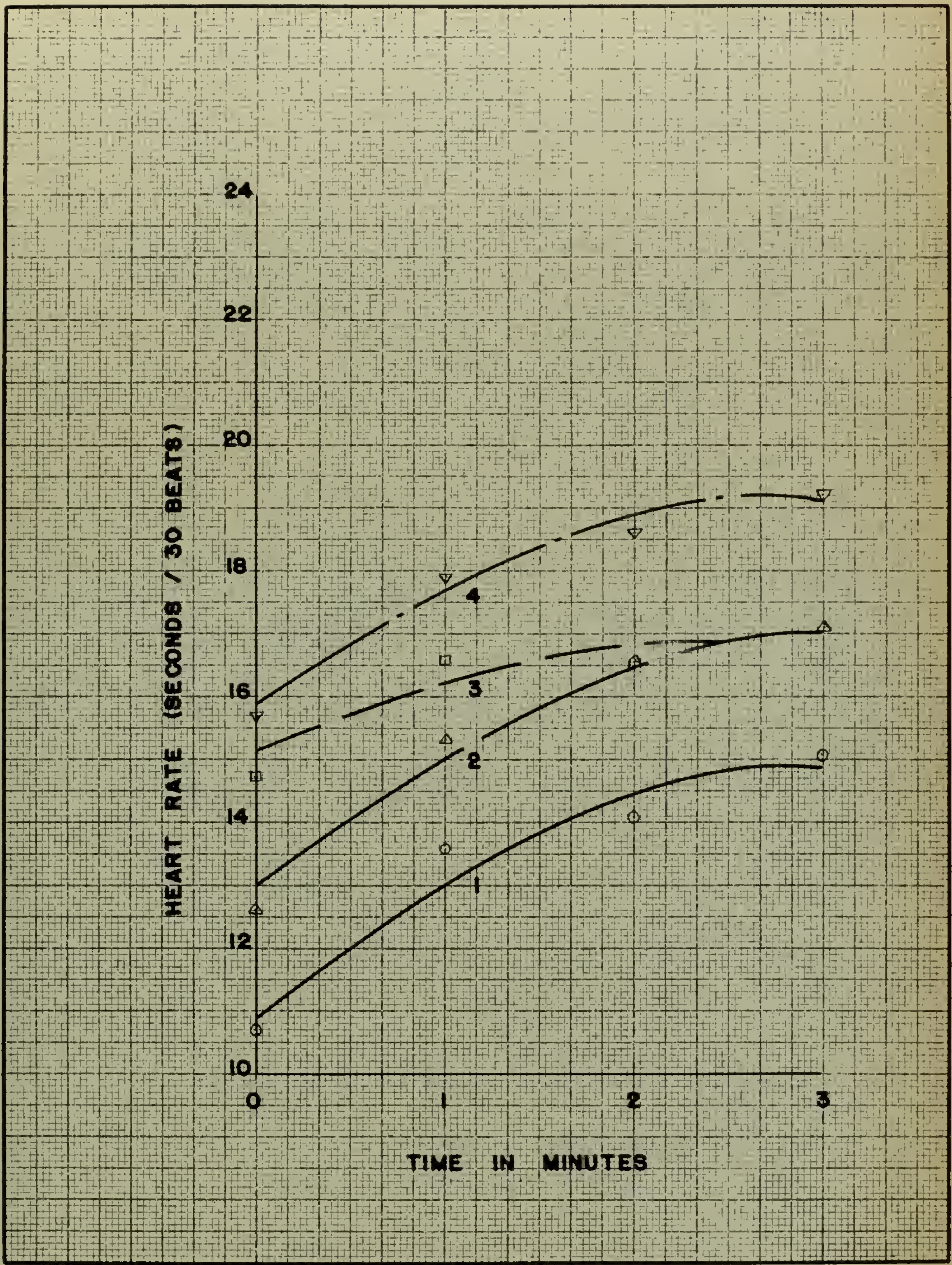

Figure 11. Heart Rate vs. Time: Operator No. 7

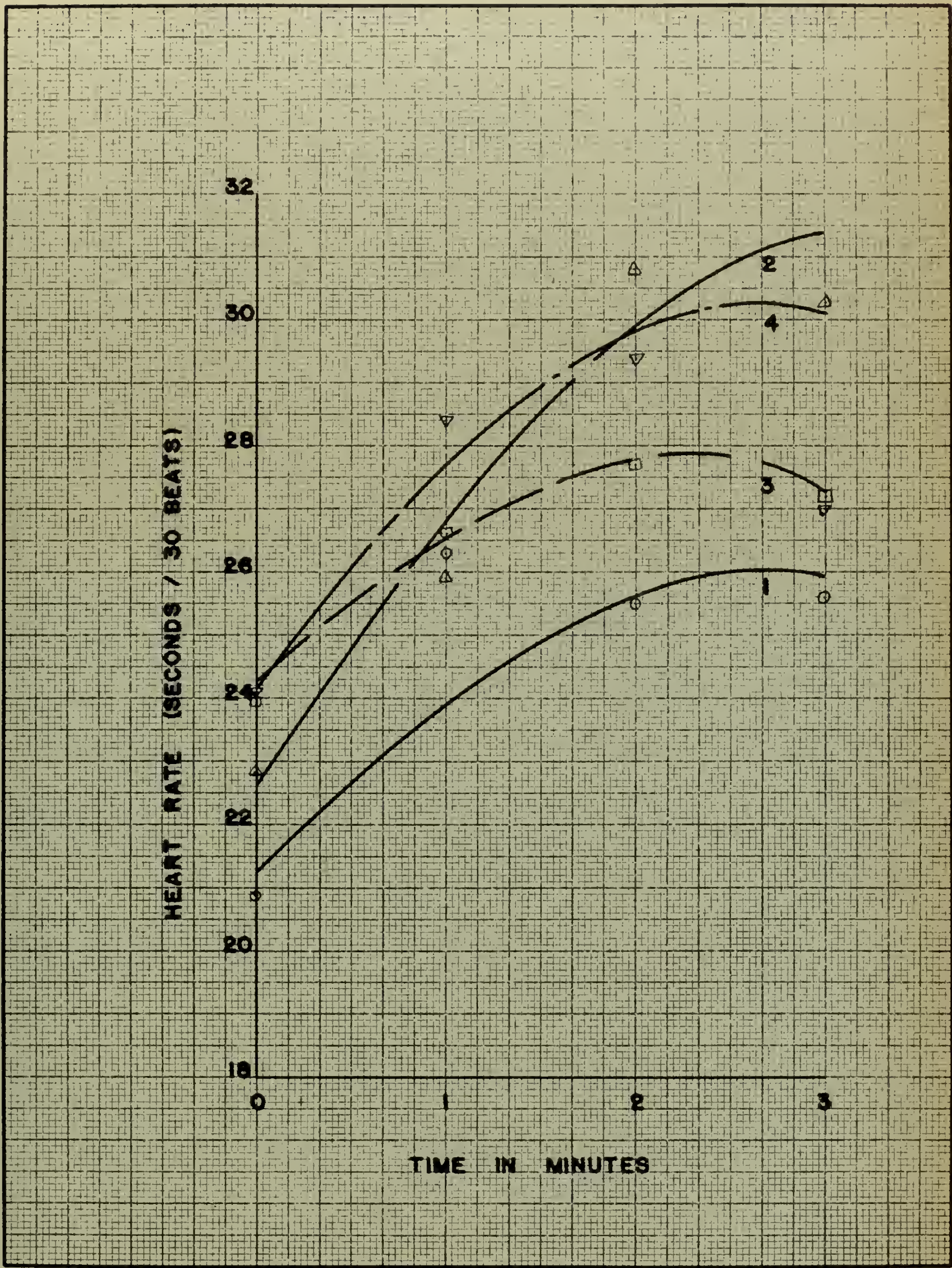

Figure 12. Heart Rate vs. Time: Operator No. 8

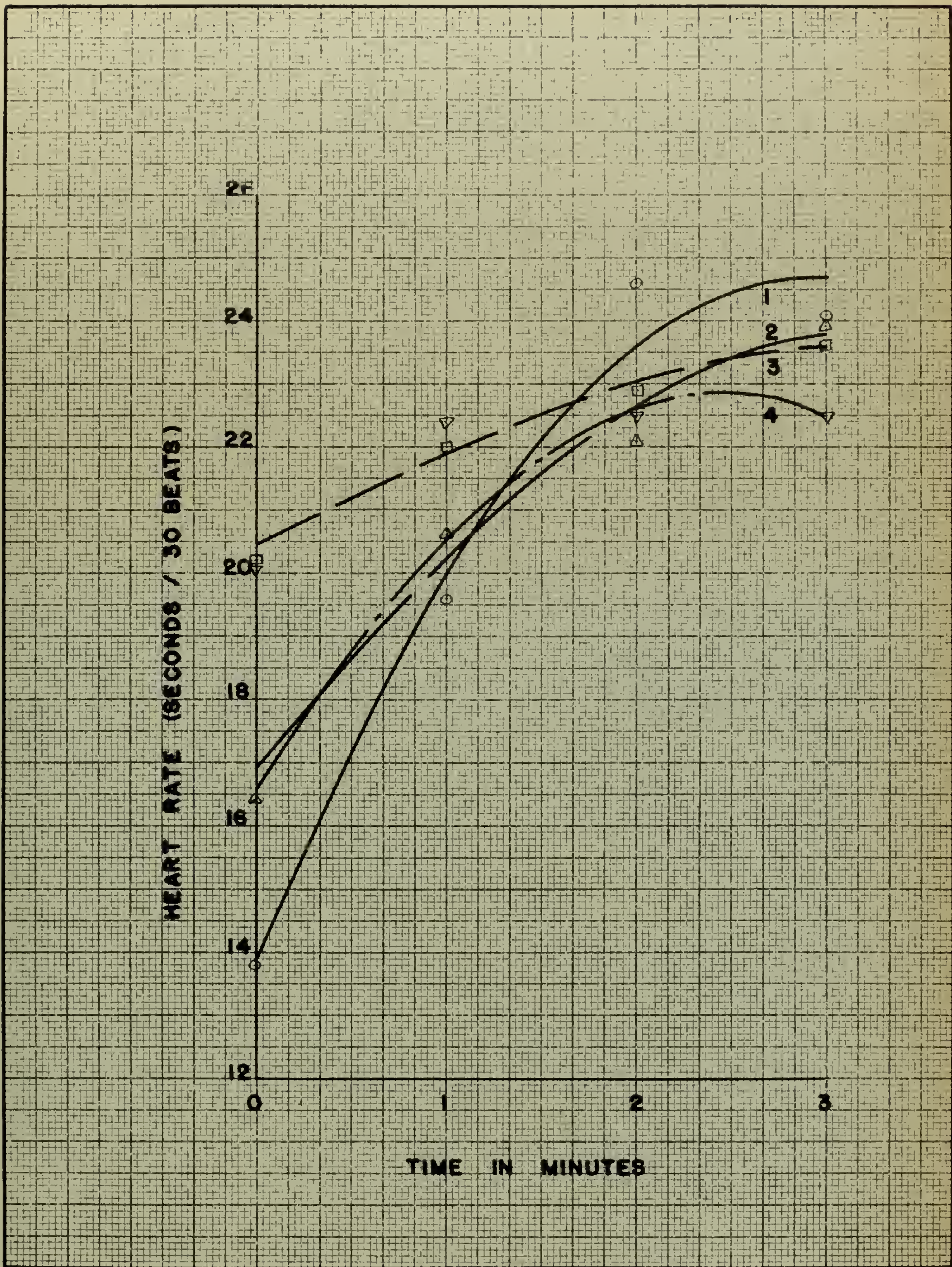

Figure 13. Heart Rate vs. Time: Operator No. 9

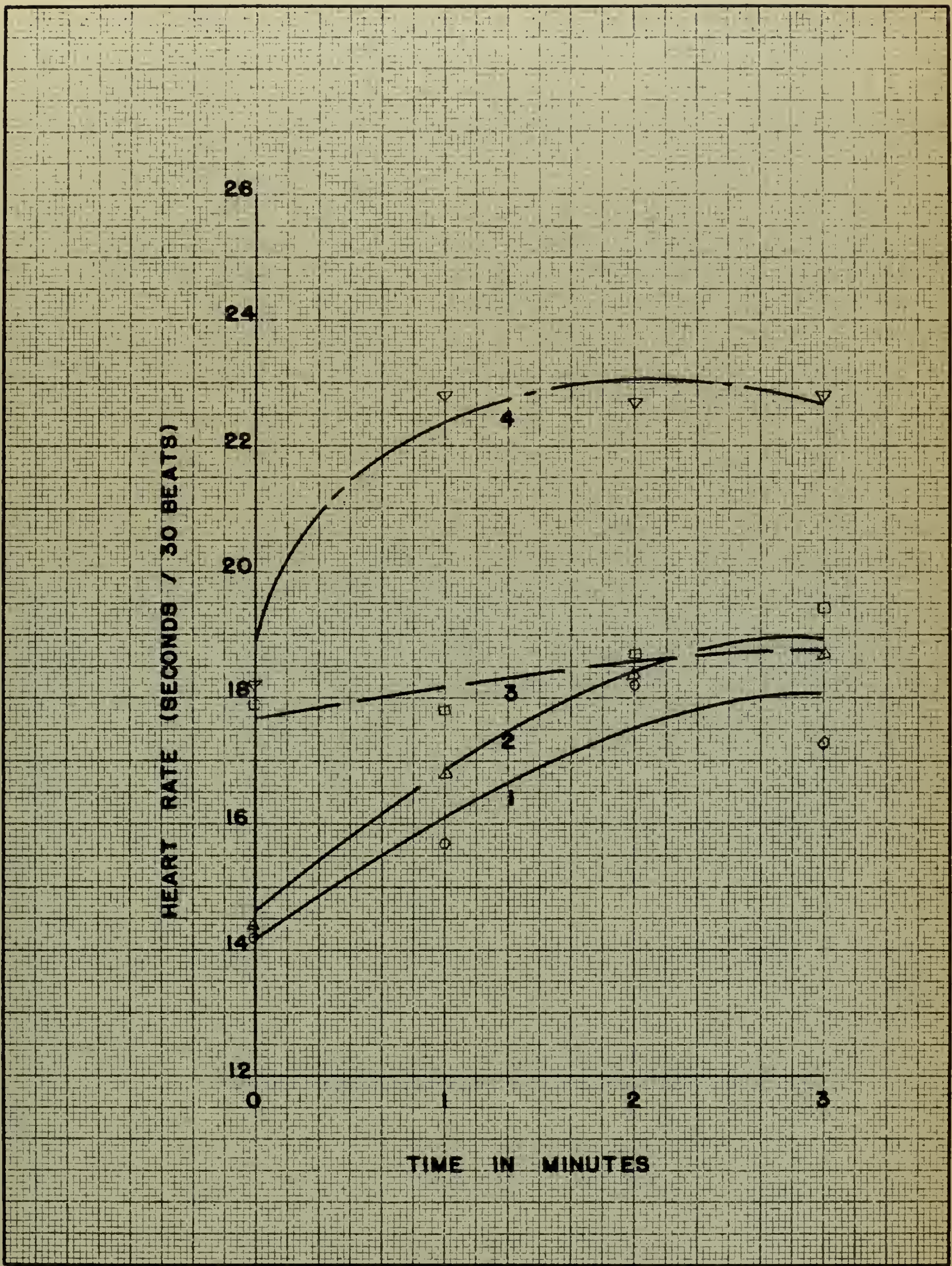

Figure 14. Heart Rate vs. Time: Operator No. 10

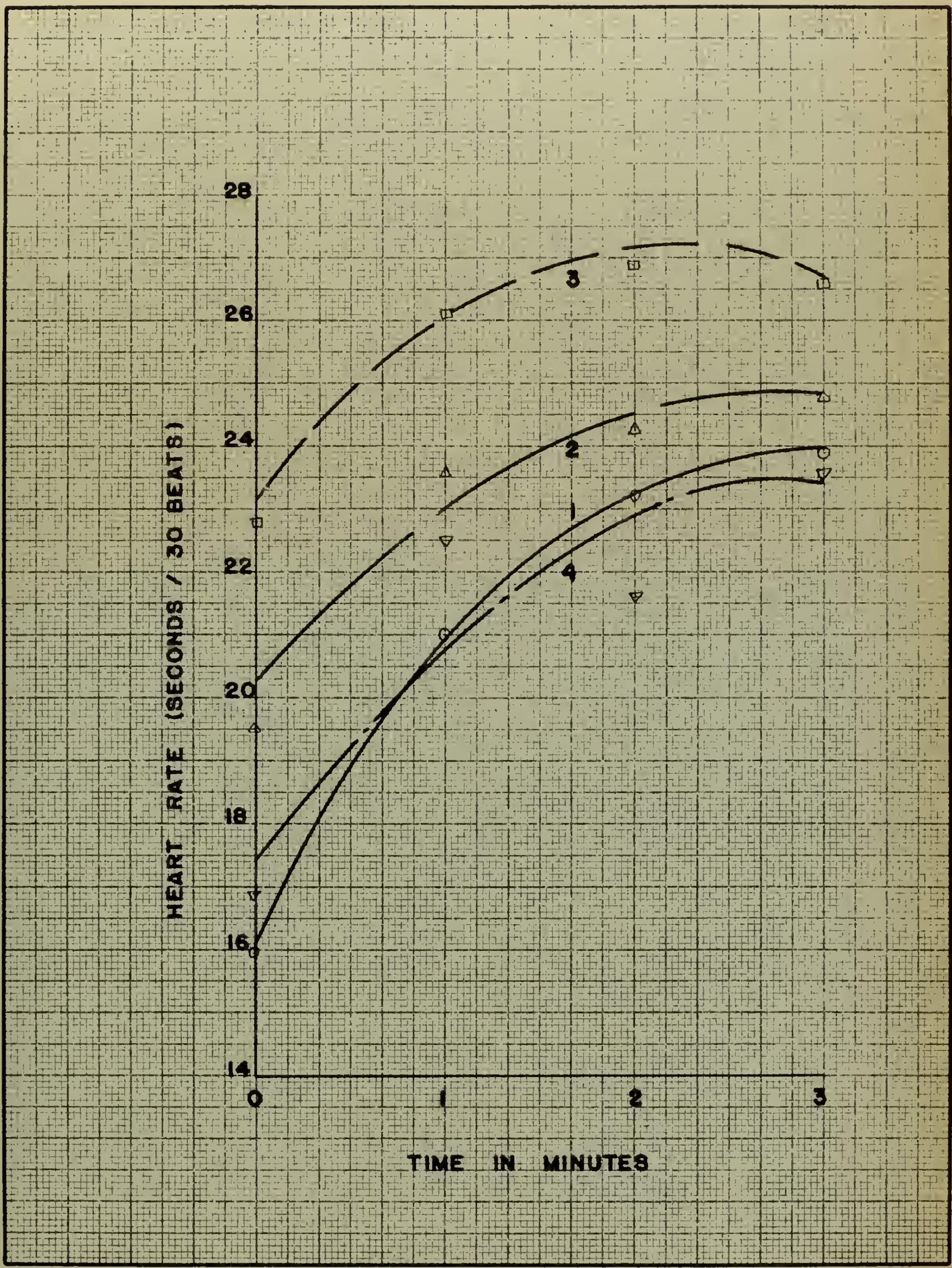

Figure 15. Heart Rate Vs. Time: Operator No. 11

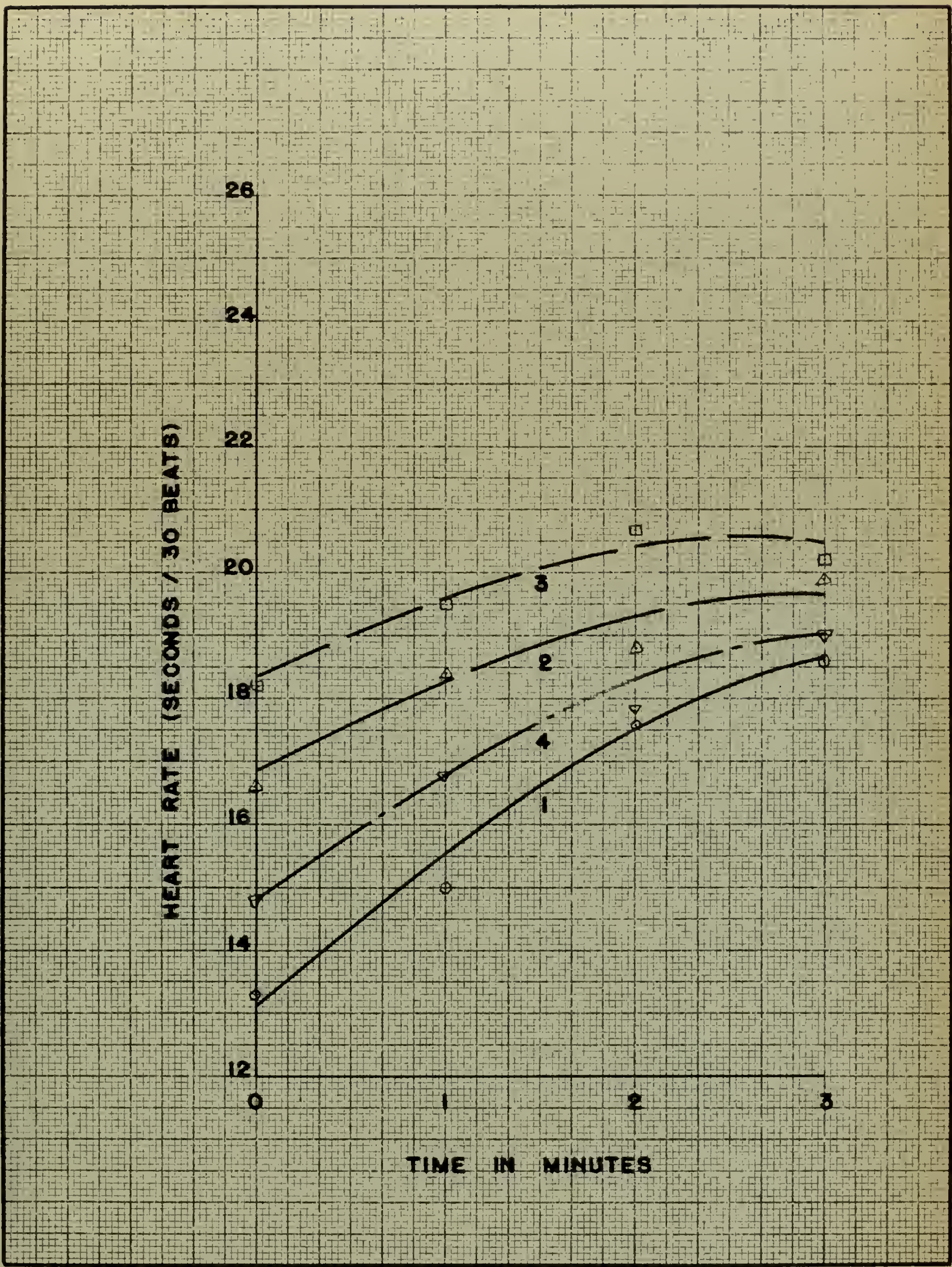

Figure 16. Heart Rate vs. Time: Operator No. 12

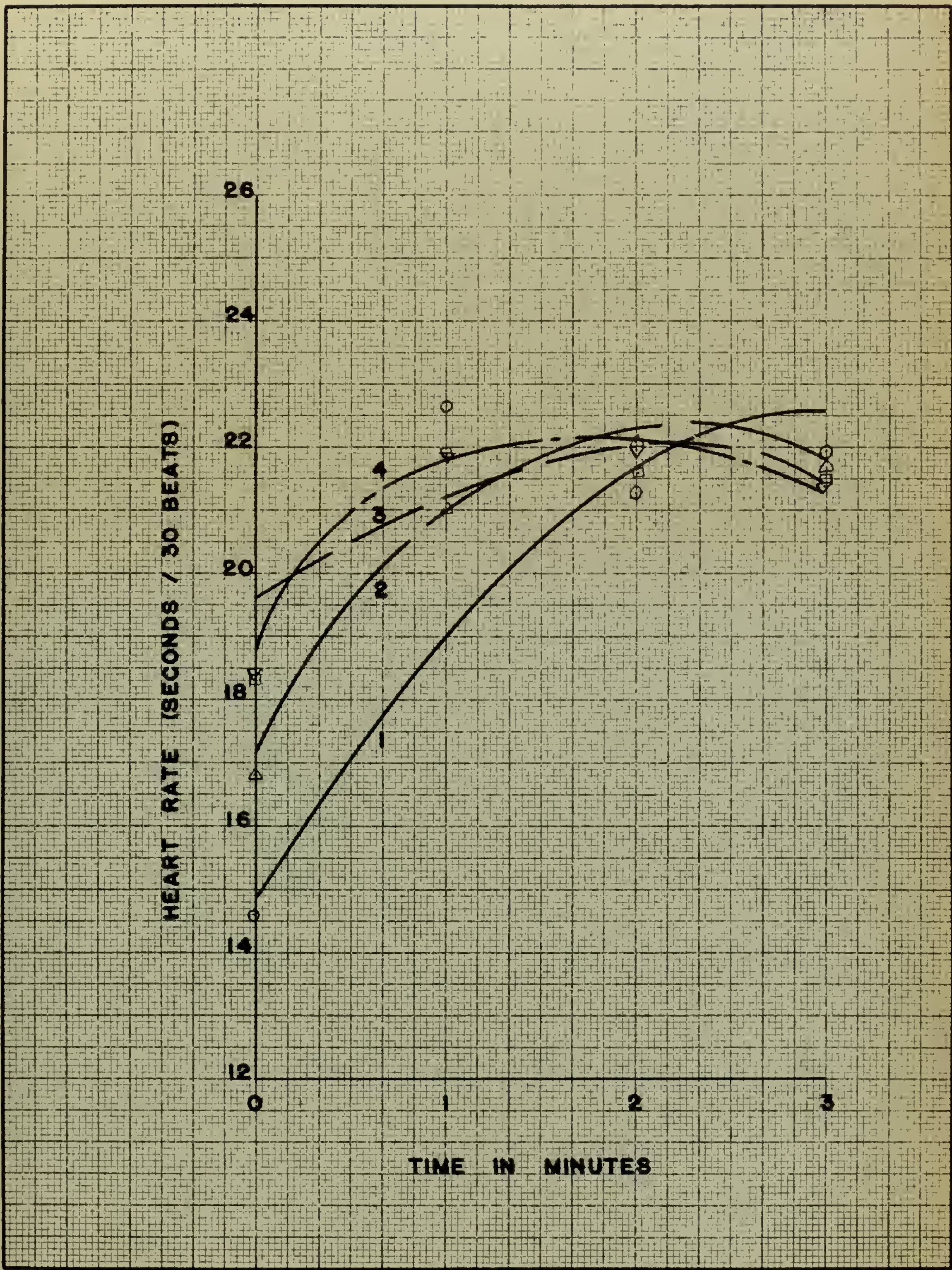

Figure 17. Heart Rate vs. Time: Operator No. 13

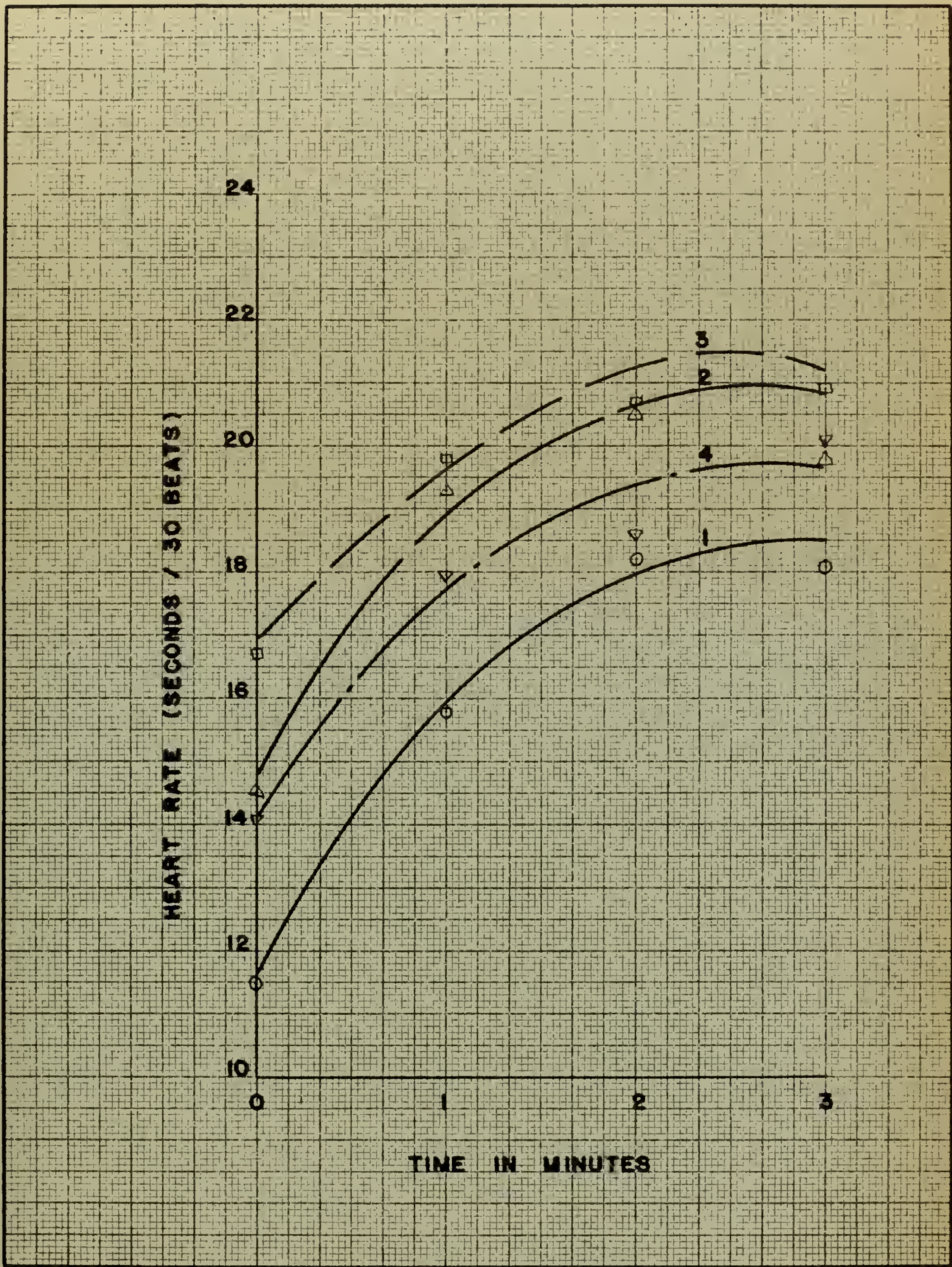

Figure 18. Heart Rate vs. Time: Operator No. 14

possibility that through insufficient training or practice these operators were not able to maintain the same pace throughout the two-minute work period. The timed pace for these operators may therefore not be indicative of the average pace during the two-minute work period.

Correlations between age and heart rate were then computed for each of the three given paces at zero time. These correlations were found to be .274, .303, and .281 for the three paces 120, 100, and 80 cycles per minute respectively. This indicates that, for the range of ages included in this group of operators, there is little or no relation between age and heart rate for any given pace. Correlations were also computed to determine the relationship between temperature and heart rate and also between humidity and heart rate. These were computed only for the 80 cycles per minute pace at zero time, as it was felt that this would be the pace that would be most affected by these factors. These correlations were found to be -.574 for the temperature effect and -.338 for humidity.

The 5 per cent significance point for a correlation based on 14 pairs of data is .532. Thus the only significant correlations are those whose value is greater than .532. It may therefore be asserted that work pace at zero time and temperature are the variables that affect heart rate based on a sample of 14 operators.

Analysis of the data obtained indicates that heart rate, measured immediately after work, can be used to predict

operator pace on the experimental task.

This investigation had the purpose of studying the relationship between heart rate recovery and work pace on a controlled task. It has been found that for purposes of determining work pace through the measure of heart rate after cessation of work, that only the zero point, i.e. the first reading, is needed and provides the highest correlation. This would indicate that future work in this area should either consider the measurement of heart rate immediately after the cessation of work, or during work with instrumentation which would permit such measurements without interfering with the operator.

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APPENDIX A

ONE WAY ANALYSIS OF VARIANCE

TABLE V

One Way Analysis of Variance

Operator Number	Pace 1	Pace 2	Pace 3	
1	12.10	15.77	21.70	
2	16.21	16.63	18.94	
3	12.96	14.30	15.90	
4	13.00	17.64	20.44	
5	14.52	17.74	19.36	
6	13.15	15.79	20.69	
7	10.66	12.58	14.75	
8	20.92	22.83	23.95	
9	13.82	16.40	20.20	
10	14.20	14.40	17.92	
11	14.96	18.50	22.76	
12	13.28	16.61	18.21	
13	14.61	16.84	18.27	Total
14	11.53	14.48	16.73	Sum
$\sum$	$X_{.1}$ 195.92	$X_{.2}$ 231.70	$X_{.3}$ 269.82	$X_{..}$ 697.44
	ΣX^2_{i1} 2,820.36	ΣX^2_{i2} 3,910.10	ΣX^2_{i3} 5,286.74	$\Sigma\Sigma X^2_{ij}$ 12,017.20

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares
Between Paces	$\Sigma n_j(\bar{X}_{ij} - X)^2$ 195.1084	$(k-1)$ 2	97.5542
Within paces or error	diff. 240.6022	$(\Sigma n_j - k)$ 39	6.1693
Total	$\Sigma\Sigma(X_{ij} - \bar{X})^2$ 435.7106	$\Sigma n_j - 1$ 41	

The ratio of: $\frac{\text{Between Paces Mean Squares}}{\text{Within Paces Mean Squares}}$ is the test ratio and should be compared with $F_{2,39}(.05)$ or 3.24. The value of the test ratio is 15.813, thus indicating a highly significant effect of pace upon heart rate.

Sample calculations:

$$\Sigma\Sigma(X_{ij} - \overline{X})^2 = \frac{3n\Sigma\Sigma X_{ij}^2 - (X..)^2}{3n}$$

$$= \frac{3(14)(12,017.20) - (697.44)^2}{3(14)} = 435.7106$$

$$\Sigma n_j(X_{ij} - X)^2 = \frac{3\Sigma X_{.j}^2 - X_{..}^2}{3n}$$

$$= \frac{3(164,873.3638) - (697.44)^2}{3(14)} = 195.1084$$

Mean Square = Sum of Squares / Degrees of Freedom

= 195.1084 / 2 = 97.5542

APPENDIX B

COMPUTATION OF CORRELATION FACTORS

CORRELATIONS

The correlation factors were found using the equation:

$$r = \frac{N\Sigma XY - \Sigma X \Sigma Y}{\sqrt{N\Sigma X^2 - (\Sigma X)^2}\sqrt{N\Sigma Y^2 - (\Sigma Y)^2}}$$

TABLE VI

Correlation Date for Pace vs. Heart Rate at "0" Time

Operator	ΣX	ΣY	ΣX^2	ΣY^2	ΣXY	r
1	6	49.57	14	865.99	108.74	.9910
2	6	51.78	14	898.04	106.29	.9291
3	6	43.66	14	639.81	90.26	.9873
4	6	51.08	14	897.96	109.60	.9900
5	6	51.62	14	900.04	108.08	.9950
6	6	49.63	14	850.03	106.80	.9903
7	6	37.99	14	489.46	80.07	.9992
8	6	67.70	14	1532.46	138.43	.9886
9	6	50.42	14	867.99	107.22	.9941
10	6	46.52	14	730.13	96.76	.8887
11	6	56.22	14	1084.69	120.24	.9886
12	6	48.10	14	783.85	101.13	.9803
13	6	49.72	14	830.33	103.10	.9922
14	6	42.74	14	622.50	90.68	.9972

TABLE VII

Correlation Data for Pace vs. Heart Rate at "1" Time

Operator	ΣX	ΣY	ΣX^2	ΣY^2	ΣXY	r
1	6	59.33	14	1219.08	127.88	.9641
2	6	54.35	14	988.34	111.59	.9972
3	6	52.77	14	935.64	109.36	.9918
4	6	56.75	14	1091.33	119.35	.9802
5	6	61.17	14	1260.19	126.45	.8081
6	6	58.89	14	1191.93	126.19	.9922
7	6	45.48	14	693.83	93.90	.9964
8	6	78.74	14	2066.92	157.74	.3629
9	6	62.24	14	1294.21	126.39	.9944
10	6	50.21	14	842.55	102.52	.9999
11	6	66.63	14	1589.16	143.42	.9958
12	6	52.87	14	942.83	110.25	.9537
13	6	65.58	14	1434.99	130.38	.4645
14	6	54.93	14	1015.36	113.89	.9200

TABLE VIII

Correlation Data for Age vs. Heart Rate at "0" Time

	ΣX	ΣY	ΣX^2	ΣY^2	ΣXY	r
At Pace 1	355	195.92	9,225	2,820.36	5,004.25	.2739
At Pace 2	355	231.70	9,225	3,910.10	5,914.54	.3027
At Pace 3	355	209.82	9,225	5,286.74	6,880.98	.2814

TABLE IX

Correlation Data for Temperature and Humidity

vs. Pace 3 at "0" Time

	ΣX	ΣY	ΣX^2	ΣY^2	ΣXY	r
Temperature	998	269.82	7,123.9	6,286.74	19,217.79	-.5736
Humidity	768	269.82	4,392.4	5,286.74	14,75[illegible]	-.3380

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